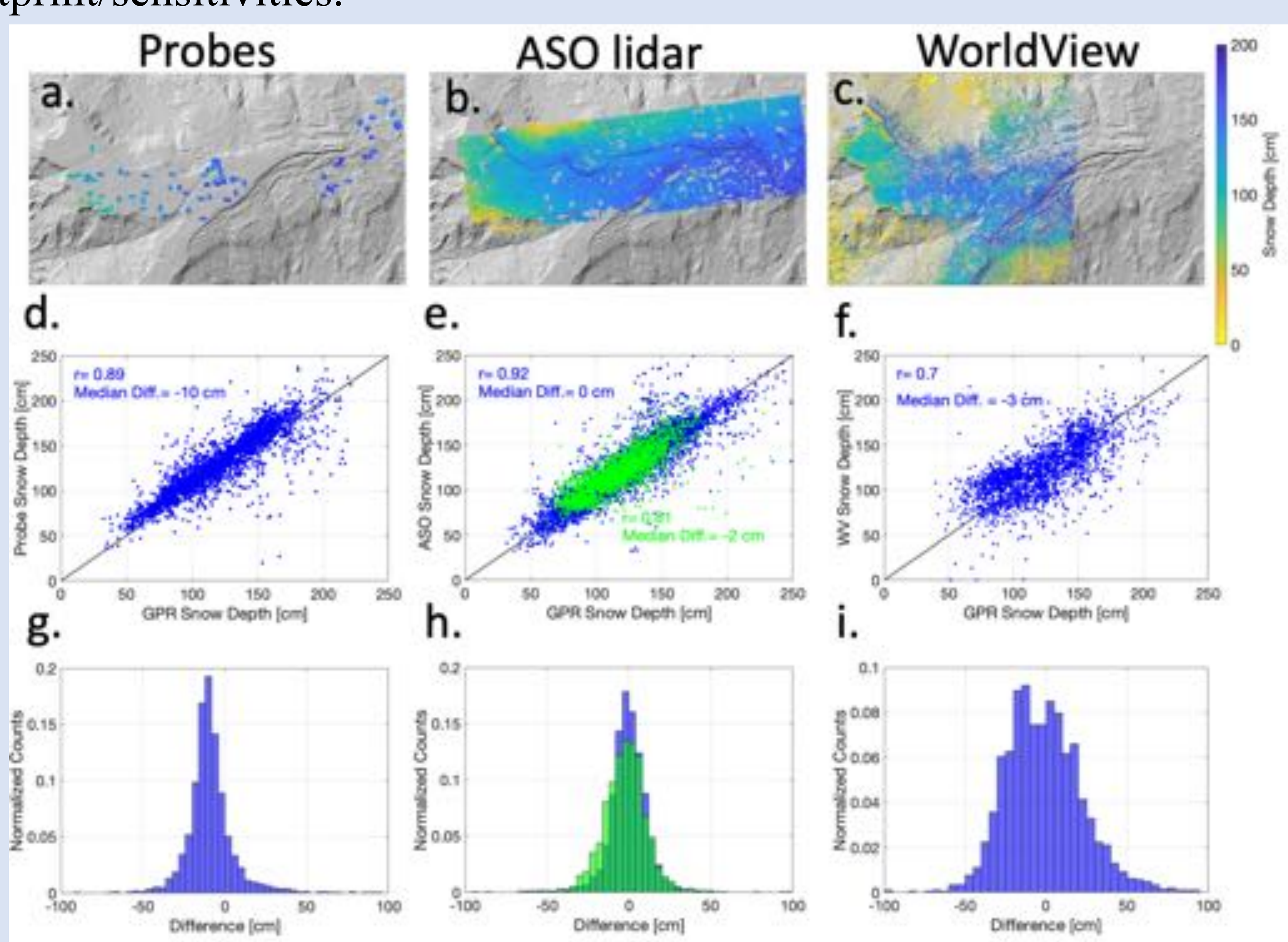
Spatially extensive ground-penetrating radar snow depth observations during NASA's 2017 SnowEx Campaign: Comparison with in situ, airborne, and satellite observations

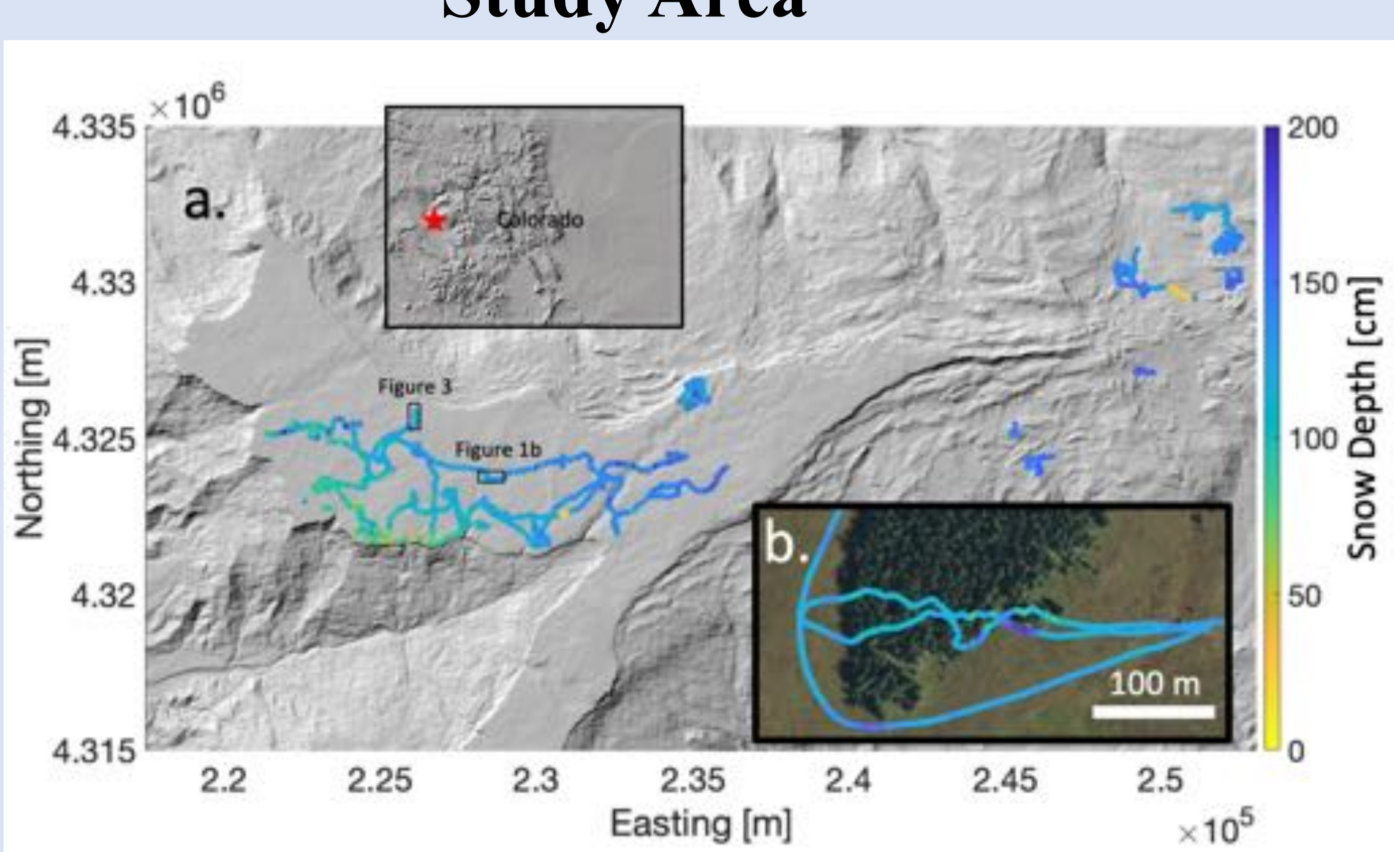
Daniel McGrath, Ryan Webb, David Shean, Randall Bonnell, Hans-Peter Marshall, Thomas H. Painter, Noah P. Molotch, Kelly Elder, Christopher Hiemstra, and Ludovic Brucker
Daniel.mcgrath@colostate.edu

Key Findings

- Ground-penetrating radar surveys during SnowEx17 provide a high-resolution (~10 cm lateral spacing), spatially extensive (1.3 million observations, 133 km of surveys), and accurate calibration/validation dataset.
- Radar-derived snow depths exhibit high to moderate correlation with three independent methods: snow probes (r=0.89, diff.= −10 cm, RMSE=18 cm), ASO airborne lidar (r=0.9, diff.= −1 cm, RMSE=14 cm) and WorldView satellite stereo imagery (r=0.7, diff.= −3 cm, RMSE=24 cm).
- Median differences between GPR and other approaches were between −1 and −10 cm.
- Observed difference between probe and GPR-derived depths likely related to probe penetration into unfrozen subsurface and differences in measurement footprint/sensitivities.

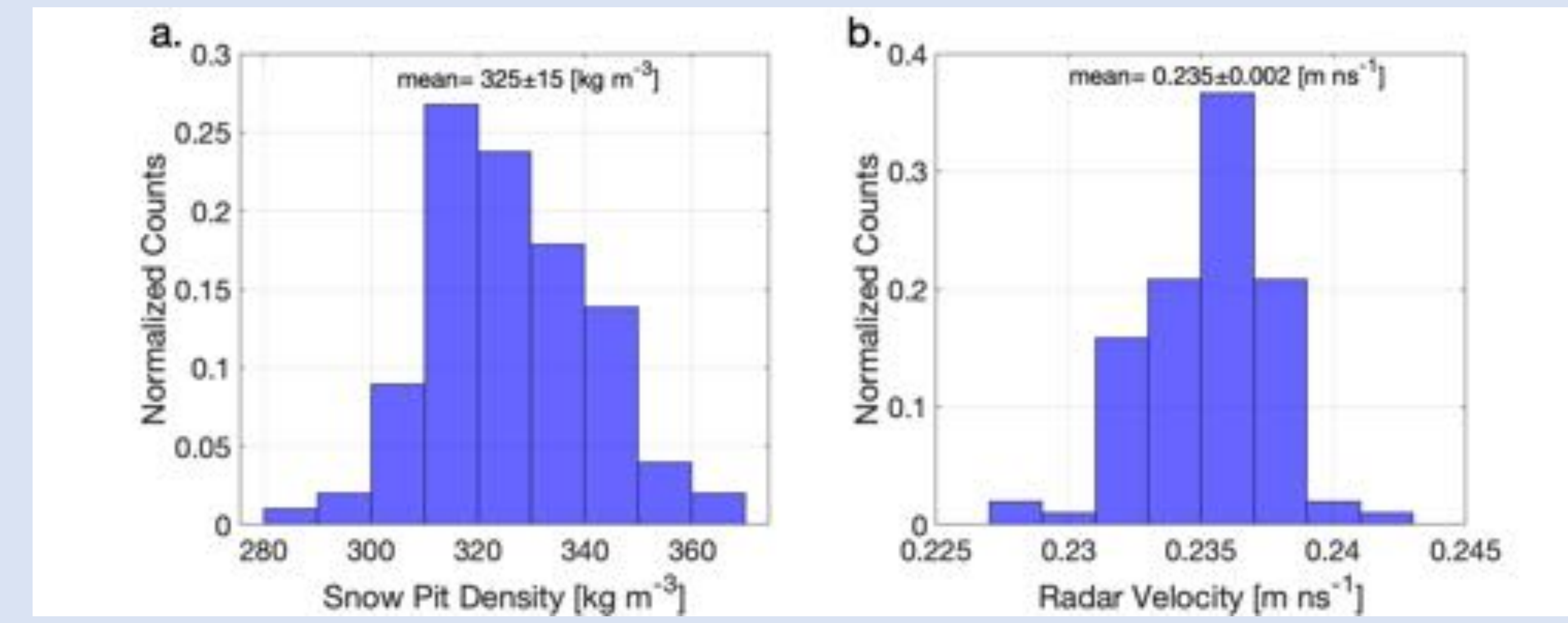


Study Area

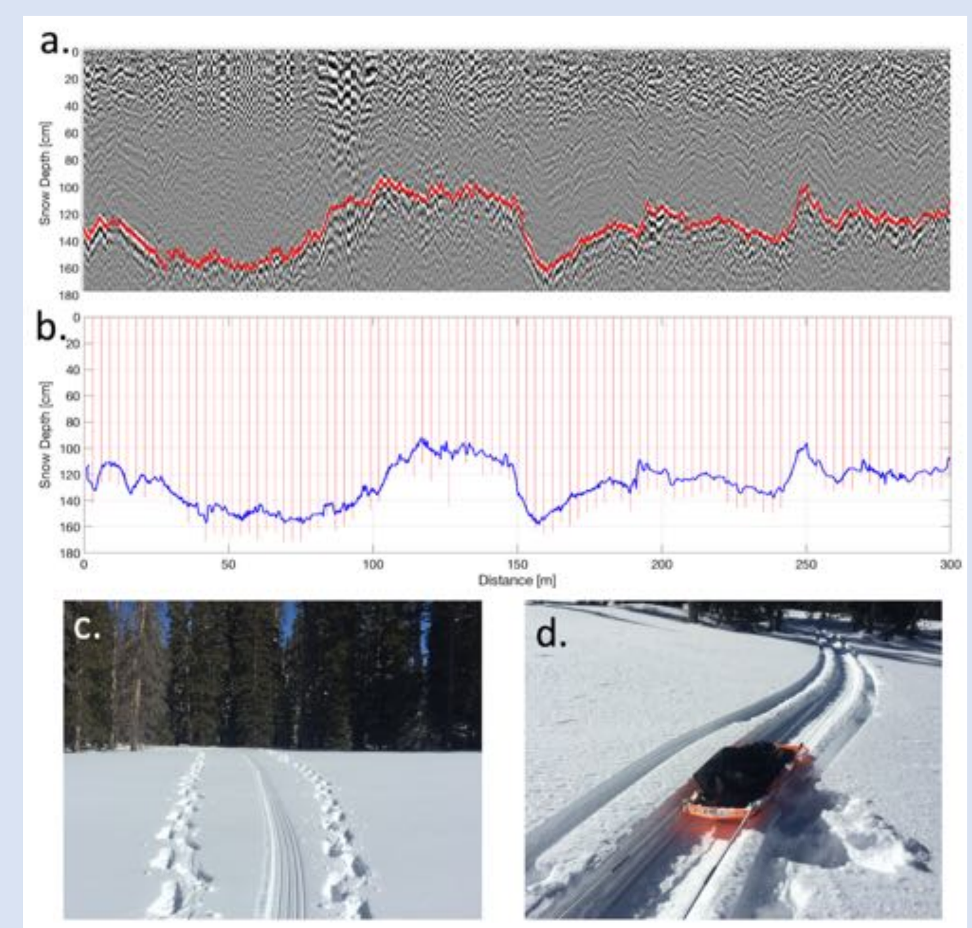


Methods

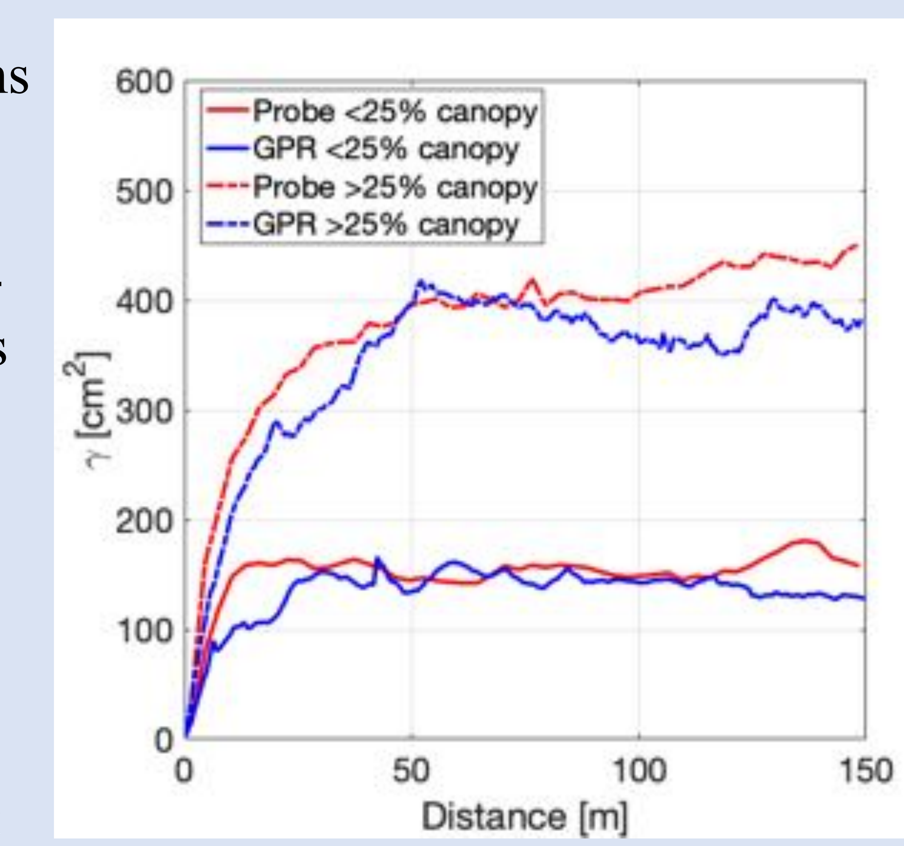
- Used ~18,000 probe measurements and 101 bulk snow densities derived from snow pits.
- Radar velocity (0.235 m/ns) from empirically derived relationship between dielectric constant and mean density.
- Temporally corrected to align with ASO and WorldView collections.



Results



- GPR observations reveal meter scale variations that are aliased by 3-m probe spacing (left).
- Computed variograms for 27 transects with 0-93% canopy cover and parsed into two groups (right).
- Transects with <25% canopy cover had a significantly lower sill, or variance, than transects with >25% cover.
- Both approaches have comparable ranges, but probe variograms have higher sills.



Discussion and Future Plans

- This GPR dataset represents a more than 50-fold increase compared to in situ depth observations collected as part of campaign, provides greater spatial coverage than terrestrial lidar, can be directly compared to InSAR phase-based approaches, and was collected at a fraction of the cost of airborne radar.
- Future campaigns should include better coordination between probe/GPR teams and include GNSS receivers to ensure better geolocation between observations, and quantification of liquid water in the snowpack, given strong impact on radar velocity.
- GPR observations will be collected during SnowEx 2020 at Cameron Pass and Grand Mesa, Colorado, Jemez River, New Mexico, and Bogus Basin, Idaho.
- These radar travel time observations will provide key in situ validation for NASA JPL UAVSAR L-band observations, which will be flown weekly to biweekly at these and other sites in the western United States between Dec. 2019 and May 2020.

Data Access

Version 1: Webb, R., D. McGrath, K. Hale, and N. P. Molotch. 2018. *SnowEx17 Ground Penetrating Radar, Version 1*. Boulder, Colorado USA. NASA National Snow and Ice Data Center Distributed Active Archive Center. doi: https://doi.org/10.5067/NPZYNEEUGQUO.

Version 2: Any day now!

Acknowledgments

Funding from NASA THP awards 80NSSC18K0877 and 80NSSC18K1405.

We thank the SnowEx leadership team and the ~100 scientists that volunteered during SnowEx 2017 campaign, without which this work would not have been possible.